The excitation of the retina caused by the stimulus of the yellowish-green light of the lime-light spectrum, reflected from "white" cardboard in 1/72 sec. (*i.e.*, 160/360 of 1/32) lasts undiminished for 5/288 sec. (*i.e.*, 200/360 of 1/32), *i.e.*, about 1/58 sec.

Taking the next point G (180°) above this last point, we find that the "last" of the stimulus of the same yellowish-green, applied for 1/64 sec. is 1/64 sec. Thus, tabulating the results for a few more points including the above two,

Stimulus for Y.G. applied	1/72	sec. lasts	5/288	; &	$288/5 \times 72/1$	$= 4147$
,, ,,	1/64	,,	1/64	,,	64×64	$= 4096$
,, ,,	1/58	,,	1/72	,,	58×72	$= 4176$
,, ,,	1/49	,,	1/92	,,	49×92	$= 4508$
,, ,,	1/40	,,	1/120	,,	40×120	$= 4800$
,, ,,	1/32	,,	1/160	,,	32×160	$= 5120$

Hence the duration of the impression on the retina *undiminished* appears to decrease as the time of stimulation increases, though within narrow limits of variation one of these quantities is nearly inversely proportional to the other.

With regard to the *total* duration of a luminous impression, the writer would point out that nothing has been said in this paper; the few experiments he has made to measure this, lead to the belief that it is almost of a different order of magnitude from the time during which an impression remains undiminished, and is to be measured by whole minutes rather than by small fractions of a second.

"On the Kathode Fall of Potential in Gases." By J. W. Capstick, M.A., D.Sc., Fellow of Trinity College, Cambridge. Communicated by Professor J. J. Thomson, F.R.S. Received May 17,—Read May 26, 1898.

It has been shown by Hittorf* that when an electric current passes through a tube containing a gas at a pressure of a few millimetres, there is a rapid fall of potential near each of the electrodes, with a much more gentle fall in the space between, and whilst the fall near the anode and in the positive column varies with the density of the gas and the current strength, the fall near the kathode is constant. Warburg† has made careful experiments on the kathode fall, and has fully established its constancy. If the gas is pure and dry, the electrodes clean, and of a metal not acted on chemically by the gas,

* 'Wied. Ann.,' vol. 20, p. 705.

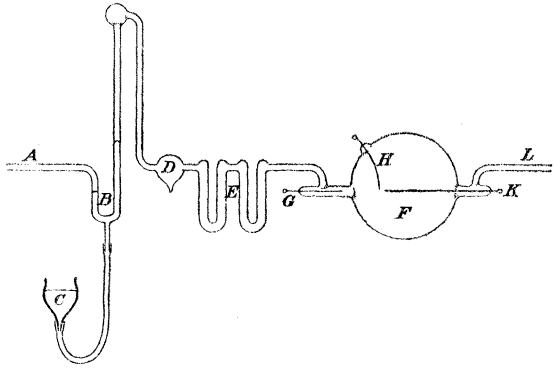
† 'Wied. Ann.,' vol. 31, p. 545; vol. 40, p. 1.

and the current not so strong as to make the negative glow cover the whole kathode or extend to the walls of the tube, the kathode fall has a definite value for each gas—a value that is independent of the pressure of the gas, or of the current strength, and that appears, in fact, to be a constant of the gas.

This being the case, it is probable that the kathode fall will prove to be connected with other physical and chemical constants of the gas, and the aim of the experiments described below was to find whether there is any intelligible relation amongst the kathode falls of three gases, one of which is formed by the combination of the other two.

The choice of suitable gases is very limited, for there must be no deposition of solid matter by the current, and no chemical action between the gas and the electrode, so that organic gases and gases containing a halogen cannot be used—at least with metal electrodes. The present investigation has been confined to water vapour, ammonia, and nitric oxide and their constituents.

The general plan of the apparatus was the same for all the gases, and is shown in the figure below.



The gas generating apparatus was sealed on at A, and a mercury pump at L. In order to isolate the generating flask from the rest, the mercury trap B was used. By raising the reservoir C, the mercury could be made to rise above the bend at B, and thus everything to the right could be exhausted. D is a small bulb to catch stray mercury. E is the purifying apparatus, and F the vessel in which the discharge took place. This vessel consisted of a globe 15 cm. in diameter, into which were sealed three wires; G, the anode of aluminium, 2 mm. thick; K, the kathode of platinum, 2 mm. thick, and extending 10 cm. into the globe, so as to afford plenty of free space for the negative glow; and H, a thin platinum wire, covered with glass to within a millimetre of the tip.

The parts of the apparatus were sealed together without glass taps or india-rubber connections.

The difference of potential to be observed is that between H and K when the current is passing between G and K. There is no need for accurate adjustment of the distance between H and K, for in the dark space the potential gradient is very slight for two or three centimetres, so that all that is required is that the end of H should be outside the negative glow. In the present experiments it was about a centimetre from the end of the kathode.

In the earlier experiments the difference of potential was measured by a bifilar quadrant electrometer, whose constant was determined by means of a battery of Clark cells. In the later experiments a Kelvin multicellular voltmeter was used.

The current through the discharge tube was supplied from 600 storage cells, a lead pencil line of variable length, drawn on a slate, being included in the circuit, to vary the current strength.

The current is not always continuous, but sometimes consists of a rapid succession of discharges, and when this is the case the observed kathode fall is not generally constant. Hence a telephone was inserted in the circuit to show when the current was continuous. With the elementary gases the telephone was generally silent, but with the compound gases the humming was so persistent as to come near wrecking the work.

Hydrogen.—Warburg found the kathode fall in hydrogen to be 300 volts, but it seemed desirable to repeat the experiments, in order to find the degree of concordance that can be obtained by different observers.

The gas was obtained from palladium that had been saturated with hydrogen prepared by the electrolysis of dilute sulphuric acid. It was purified by solid potash and phosphoric anhydride, and the discharge tube contained a piece of sodium, to destroy the last traces of moisture. The apparatus was repeatedly exhausted, heated, and refilled with hydrogen, whilst the electrodes were kept red hot by a strong current, to expel occluded gases.

The strength of the current was not measured during the experiments, but it was varied by altering the resistance in the circuit, so as to cover a varying length of the kathode with the negative glow, and so to show whether the tube was large enough to allow the discharge to pass without hindrance. The table below gives details of the measurements.

The first column gives the pressure of the gas in millimetres of mercury, the second gives the fraction of the kathode that was covered with the glow, and the third gives the kathode fall in volts.

p.	Glow.	E.
6	$\frac{1}{2}$	298
Apparatus exhausted and refilled.		
5	$\frac{2}{3}$	304
Apparatus exhausted and refilled.		
2	$\frac{4}{5}$	298
2	$\frac{1}{2}$	296
2	$\frac{1}{3}$	298
More gas admitted without exhausting.		
4	$\frac{4}{5}$	297
4	$\frac{1}{3}$	296

The mean result is 298 volts, which agrees so closely with the value 300 found by Warburg, that no further experiments were made.

Oxygen.—The gas was made by heating permanganate of potash, and passed through a set of Geissler bulbs of sulphuric acid and over lumps of potash and phosphoric anhydride before reaching the discharge tube. The permanganate was twice recrystallised, dried, and heated till it fell to a fine powder, before being introduced into the apparatus, in order to ensure the absence of moisture, and so diminish the risk of formation of volatile manganese compounds.

The degree of purity of the gas was tested by the spectrum of the discharge, and it proved a difficult matter to get rid of the nitrogen. By repeatedly exhausting and filling the apparatus with oxygen while the glass was kept hot, the nitrogen lines were rendered very faint, but they were not entirely removed even after continuing the operations for a fortnight. The hydrogen lines soon disappeared entirely, but the nitrogen lines were always faintly visible when the current was strong enough to make the kathode red hot. As, however, a very small amount of nitrogen is sufficient to make the nitrogen lines far brighter than the oxygen lines, the quantity of nitrogen present must have been extremely small.

In the observations recorded below, from two to six readings with different current strengths were taken at each pressure. The mean result is given for each set.

p.	E	
11	370	
7	371	
4	363	
$2\frac{1}{2}$	370	
$1\frac{1}{2}$	373	Mean, 369

The tube was then heated, exhausted, and refilled several times, and a similar set of readings taken.

p.	E.	
12	370	
$9\frac{1}{2}$	372	
7	368	
$4\frac{1}{2}$	360	
$3\frac{1}{2}$	364	
3	374	
$2\frac{1}{2}$	374	
2	374	
$1\frac{1}{2}$	373	
1	373	Mean, 370

The mean of the whole is 370 volts.

Nitrogen.—Warburg's determination of the kathode fall in this gas was made on atmospheric nitrogen containing argon, and hence it was necessary to repeat the observations on chemically prepared nitrogen.

In the first experiments the gas was prepared by heating ammonium bichromate. If the bichromate is mixed with fine sand the decomposition is easily controlled, but the gas is impure, and must be passed over ignited copper and copper oxide, which involves the use of hard glass and india-rubber connections. The joints were very carefully made with thick-walled soft rubber tube, yet the observed kathode fall, 355 volts, was the same as in air, and nearly the same as in oxygen, and very much higher than what later experiments showed was the true value for nitrogen. The result is interesting, as showing the great effect of a small quantity of oxygen in the nitrogen, and emphasises the necessity for scrupulous care in removing traces of impurity.

The final experiments were made on gas prepared by the decomposition of ammonium nitrite. A solution of pure ammonium chloride was contained in a flask from the neck of which a tube a yard long passed downwards into a mercury reservoir. When the flask was exhausted along with the rest of the apparatus, potassium nitrite solution could be sucked in as required by pouring a little on the top of the mercury, and lowering the reservoir. At low pressures the mixture of ammonium chloride and potassium nitrite does not require heating, as the nitrogen comes off regularly and very slowly at the temperature of the room.

The gas was passed over solid potash and phosphoric anhydride, and a piece of sodium was placed in the discharge tube.

In some of the experiments bichromate of potash was also added to oxidise to nitric acid any oxides of nitrogen that might be formed. The addition made the evolution of gas inconveniently rapid, and the flask had to be kept cool by a water bath. The

difference between the measurements before and after the addition was very small.

It is not necessary to give a detailed list of all the observations that were made. It will be sufficient to say that before the bichromate was added twenty-five observations were made, the mean value found for the kathode fall was 231 volts, the extreme values being 223 and 241. After the addition of the bichromate twenty measurements were made, the mean value being 233 and the range 225 to 238. The mean of the whole is 232.

This is exactly the same as Warburg found for atmospheric nitrogen, whence it appears that the presence of argon has no effect on the kathode fall.

Water Vapour.—Distilled water from a clean silver still was boiled to remove dissolved gases, and the apparatus was sealed up whilst the water was still at the boiling temperature.

The greater part of the air was removed from the apparatus by means of the pump, which contained some sulphuric acid above the mercury, and the whole was then allowed to stand for a week, the acid absorbing the vapour and keeping up a steady evaporation of the water, thus gradually sweeping out any remaining air. The uncondensed gas was ejected from the pump, and the acid renewed from time to time. Incondensable gas never entirely ceased to pass over, but before any experiments were made it appeared from an estimate of the volume of water absorbed by the acid and the volume of the air bubble in the pump, that the ratio of the pressure of the air to the pressure of water vapour in the apparatus was reduced to about one part in five millions. Of course, more gas came over when the discharge was passing, but even then the quantity was very small. Presumably the hydrogen and oxygen set free near the electrodes recombine at other parts of the tube.

A compound gas naturally presents difficulties that are absent in the case of an elementary gas, for as soon as the current is started the gas becomes mixed with decomposition products, and is no longer pure. The chief difficulty, however, arose from the intermittence of the current. With elementary gases the current was seldom intermittent, with the compound gases it was seldom constant. It was, of course, useless to take any readings of the kathode fall when the telephone was singing, and many months were spent in a fruitless attempt to find what circumstances determine the constancy or intermittence of the current.

The rate of intermittence was not usually constant, as was evident from the variation in the note given by the telephone, and the change from sound to silence was sudden, and often accompanied by other changes, such as the appearance of striæ in the tube, and a sudden change in the kathode fall. When the telephone was silent

it could always in the case of the compound gases be made to sing by a sufficient increase in the current, but a reduction of the current density by the use of electrodes half an inch in diameter made it no easier to obtain a constant current.

The method by which it was hoped that errors due to the decomposition of the gas would be got rid of was to start the current, and when by accident as it proved rather than by design, the telephone was silent, to open the mercury trap and allow a stream of pure gas to play on the electrodes, whilst the reading of the electrometer was taken. It was not often that this could be carried out, for when after repeated attempts the telephone was silenced, the usual result of admitting fresh gas was either to make the current intermittent or to stop it altogether.

The proceeding was carried out successfully only twice. In the first experiment the current was steady as soon as the circuit was closed. The negative glow covered half the kathode and the kathode fall was 471 volts, but quickly rose to 484 as decomposition proceeded. A little vapour was then admitted, and the fall of potential at once sank to 467 but soon rose again to 482 when the stream of gas ceased. More vapour was then admitted whereupon the kathode fall sank to 469, and in half a minute rose again to 478.

The second experiment was less satisfactory as only a single reading was obtained. After the current had been running for a few minutes the telephone became silent, the negative glow consisting of a bright tip covering about a tenth of the kathode and the kathode fall being 484. On admitting more vapour it sank to 469, but before it had risen more than a few volts the telephone began singing again, and could not be made to stop.

Thus we have four observations of the kathode fall in the undecomposed gas, namely: 471, 467, 469, and 469, the mean being 469.

In both experiments the pressure of the vapour was about 2 mm.

Ammonia.—The gas was prepared by the action of soda on ammonium sulphate that had been treated with nitric acid in the ordinary way to remove organic substances. The ammonia was dried with lime and absorbed in calcium chloride contained in a bulb sealed to the apparatus.

Here, as with water vapour, the numerous attempts to secure a constant current met with little success. Only two readings of the kathode fall were obtained, and these were not very concordant. In the first experiment the current had been running for half an hour when the intermittence ceased, and the kathode fall in the partially decomposed gas was 510 volts. When a stream of pure ammonia was allowed to play on the kathode, the reading of the electrometer rose to 595, where it remained steady until, after a few seconds, the dis-

charge stopped. In the second experiment the current had been running for some time through gas at a low pressure, the kathode fall being 440 volts. A stream of pure gas sent it up to 570, but the telephone soon began singing, and the kathode fall sank rapidly to 480. The mean of the two observations is 582 volts.

Nitric Oxide.—A mixture of nitre and ferrous sulphate was acted on by dilute sulphuric acid, and the evolved gas washed with potash solution and sulphuric acid, and absorbed in a saturated solution of ferrous sulphate. This solution was contained in a flask, sealed to the rest of the apparatus. The gas was given off readily without warming when the pressure was sufficiently reduced, and was passed over potash and phosphoric anhydride before reaching the discharge tube.

In the case of water vapour and ammonia, when the current was discontinuous the observed kathode fall was very variable and not independent of the current strength, but with nitric oxide the variation was within narrow limits, the readings always lying between 340 and 380 volts, whether the telephone was silent or not, and whatever the current strength, provided the kathode was not covered with the negative glow.

The readings of the kathode fall and the appearance of the discharge showed that the gas is rapidly decomposed by the current. When the discharge first started, the kathode fall was always near 370 volts, and the glow at both anode and kathode was white. In a few seconds the glow round the kathode began to grow blue, and that round the anode turned pink, whilst the kathode fall slowly sank to about 345 volts. Meanwhile the glow spread backwards along the kathode, showing an increase of current, and hence a decrease in the resistance of the gas.

The decomposition proceeded so rapidly that it was impossible to get the kathode fall for the pure gas by taking the reading whilst a stream of gas played on the electrodes, for the strength of stream necessary to maintain the white glow of the pure gas was so great that the pressure immediately rose high enough to stop the discharge. Hence the only feasible plan was to allow the gas to stream through the tube long enough to sweep out the products of decomposition, then stop the stream by closing the mercury trap, pump down to a suitable pressure, start the discharge, and take a reading as quickly as possible.

Twelve readings were taken in this way, when the telephone was either silent throughout or became silent a few seconds after the current started. There was never any change in the kathode fall at the moment when the current became constant. The readings varied between 366 and 378, the mean value being 373.

This is so nearly the value for oxygen as to suggest a doubt of its

accuracy. The earlier experiments on nitrogen showed that a very slight trace of oxygen was sufficient to raise the kathode fall from its true value 232 to 355. In fact, the values for oxygen, nitric oxide, air, and nitrogen with a trace of oxygen, are all nearly the same, which makes it not improbable that in each case the oxygen alone acts as the carrier of the current.

We have, then, finally the following values for the kathode fall—

Hydrogen	298
Nitrogen	232
Oxygen	369
Water vapour	469
Ammonia	582
(Nitric oxide	373)

The last is enclosed in brackets in consequence of the doubts as to its accuracy. If we leave the result for this last gas out of account, it appears that the kathode fall is approximately an additive quantity. Ascribing the values 149, 116, and 184 respectively to the atoms of hydrogen, nitrogen, and oxygen, we get, by addition, 482 for water vapour and 563 for ammonia. As each of these depends on three measurements, they may be taken as agreeing with the observed values within the limits of experimental error. Hence, so far as the evidence of these experiments goes, the kathode fall is a property of the atoms rather than of the molecule.

As the kathode fall is constant for all pressures and currents whilst the potential gradient along the rest of the tube is variable, we may infer that no potential difference less than the kathode fall is capable of causing a discharge through the gas. This conclusion is consistent with the experiments of Mr. Peace,* who found that the minimum difference of potential that gives a discharge in air is something over 300 volts.

Assuming that the conduction is electrolytic, it seems likely, from the analogy of the electrolysis of liquids, that the kathode fall may prove to be a measure of the energy required to dissociate the gas into the ions that carry the electricity, and the present experiments were undertaken in the hope of finding some confirmation of this hypothesis. They have not, however, provided the kind of evidence that was anticipated. The results can only be reconciled with the hypothesis if further assumptions are made that would put the conduction in gases on a very different footing from the electrolytic conduction of liquids. The additive nature of the kathode fall might, for instance, be taken as an indication that the carriers of the current are provided by the disintegration of the atoms into much

* 'Roy. Soc. Proc.,' vol. 52, p. 99.

smaller particles, as has already been suggested by J. J. Thomson from entirely different evidence; but the results are too few to make further speculation on their meaning of much value.

"Note on the Complete Scheme of Electrodynamic Equations of a Moving Material Medium, and on Electrostriction." By Joseph Larmor, F.R.S., Fellow of St. John's College, Cambridge. Received May 17,—Read May 26, 1898.

This note forms a supplement to my third memoir on the "Dynamical Theory of the Æther,"* to the sections of which the references are made.

1. It is intended in the first place to express with full generality the electrodynamic equations of a material medium moving in any manner, thus completing the scheme which has been already developed subject to simplifying restrictions in the memoirs referred to. To obtain a definite and consistent theoretical basis it was necessary to contemplate the material system as made up of discrete molecules, involving in their constitutions orbital systems of electrons, and moving through the practically stagnant æther. It is unnecessary, for the mere development of the equations, to form any notion of how such translation across the æther can be intelligibly conceived: but, inasmuch as its strangeness, when viewed in the light of motion of bodies through a material medium and the disturbance of the medium thereby produced, has often led to a feeling of its impossibility, and to an attitude of agnosticism with reference to æthereal constitution, it seems desirable that a kinematic scheme such as was there explained, depending on the conception of a rotationally elastic æther, should have a place in the foundations of æther-theory. Any hesitation, resting on *à priori* scruples, in accepting as a working basis such a rotational scheme, seems to be no more warranted than would be a diffidence in assuming the atmosphere to be a continuous elastic medium in treating of the theory of sound. It is known that the origin of the elasticity of the atmosphere is something wholly different from the primitive notion of statical spring, being in fact the abrupt collisions of molecules: in the same way the rotational quality of the incompressible æther, which forms a sufficient picture of its effective constitution, may have its origin in something more fundamental that has not yet even been conceived. But in each case what is important for immediate practical purposes is a condensed and definite basis from which to develop the interlacing ramifications of a physical scheme: and in each case this is obtained by the use of a representation which a deeper knowledge may after-

* 'Phil. Trans.,' A (1897).